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**THERMAL CONDUCTIVITY OF A PARTICULATE SAMPLE  
IN AN ENVIRONMENT THAT SIMULATES THE PLANET MARS**

By James A. Fountain and Ronald W. Scott  
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### ABSTRACT

A series of thermal conductivity tests has been conducted on a particulate sample in an environment that simulates the planet Mars with respect to atmospheric constituency, pressure, and temperature range. The results establish an order of magnitude for this type of sample-environment system. The thermal conductivity lies in the range from  $1.53 \times 10^{-4}$  watt/cm $^{\circ}$ K at the minimum temperatures to about  $2.35 \times 10^{-4}$  watt/cm $^{\circ}$ K at the maximum temperatures. The effect on the thermal conductivity caused by pressure is compared between a sample in Martian and lunar type environments. The effects of temperature cycling on the shape of the thermal conductivity curve are also discussed.

GEORGE C. MARSHALL SPACE FLIGHT CENTER

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SPACE SCIENCES LABORATORY**



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# THERMAL CONDUCTIVITY OF A PARTICULATE SAMPLE IN AN ENVIRONMENT THAT SIMULATES THE PLANET MARS

## SUMMARY

A series of thermal conductivity tests has been conducted on a particulate sample in an environment that simulates the planet Mars with respect to atmospheric constituency, pressure, and temperature range. The results establish an order of magnitude for this type of sample-environment system. The thermal conductivity lies in the range from  $1.53 \times 10^{-4}$  watt/cm $^{\circ}$ K at the minimum temperatures to about  $2.35 \times 10^{-4}$  watt/cm $^{\circ}$ K at the maximum temperatures. The effect on the thermal conductivity caused by pressure is compared between a sample in Martian and lunar type environments. The effects of temperature cycling on the shape of the thermal conductivity curve are also discussed.

## INTRODUCTION

In recent years, significant effort has been expended to learn more about the thermal properties of the planets. A test series consisting of one hundred differentiated line heat source (DLHS) thermal conductivity tests has been conducted on a sample of spherical glass particles in a simulated Martian environment to establish an order of magnitude for some of the thermal problems associated with a Martian-like surface. This type of sample was chosen for these initial tests because of its general use as a standard sample by investigators in the field of thermal conductivity of particulate media [1], and also because there is no preponderance of evidence as to specific mineral types for Mars. This work is a continuation of similar work done in the Space Sciences Laboratory on the same sample for lunar simulations, and comparison will be made on the results between Martian and lunar conditions.

The test procedure used was designed (1) to establish a clean sample, (2) to measure the thermal conductivity of the sample under conditions of a clean vacuum over the desired temperature range, (3) to introduce carbon



dioxide into the system to the desired Martian atmospheric pressure (allowing sufficient time for diffusion into the sample), and (4) to measure the thermal conductivity under these conditions.

The testing was performed in an ionization vacuum system in which the preliminary pumping was done by oil-free cryogenic sorption pumps to insure that the effects of impurities and extraneous materials were reduced to a minimum. The sample was baked for 48 hours at 250°C in the two 24-hour periods. This bakeout was done during the initial ionization pumping to remove the impurities as they were baked from the sample.

## THE MARTIAN ENVIRONMENT AND SAMPLE SIMULATION

Mars has been studied extensively by ground-based telescopic investigations and space-borne probes. The model chosen for this test series was based on a near-infrared spectroscopic study of the CO<sub>2</sub> absorption lines near 8700 Å by Spinrad and others [2]. It combines their own observations made at the McDonald and Lick observatories with observations by Sinton and Kuiper, and with the results of the Mariner IV occultation experiment. The conclusion was that the Martian atmosphere is almost entirely carbon dioxide and the atmospheric pressure is approximately 7 mb. Accordingly, the authors used 100 percent CO<sub>2</sub> and have assumed that traces of other atmospheric gases would not be significant with respect to their contribution to thermal conductivity.

The temperature range on Mars was established by Sinton and Strong [3] and Gifford [4]. Gifford analyzed over 1300 infrared observations taken by Lampland at the Lowell Observatory. He established maximum and minimum yearly temperature variations of 300°K and 220°K, measured to ±70° latitude. Sinton and Strong, using measurements from the 200-inch reflector at Mt. Palomar, calculated a diurnal range of 306°K to 203°K. The temperature of the author's sample was controlled by circulating either liquid nitrogen or hot oil through tubing, which was coiled throughout the sample holder. The temperature ranges of the tests exceeded these limits at both extremes.

The Mariner photographs have indicated a lunar-type landscape for Mars with a cratered surface, so it was reasonable to assume that the Martian surface layer is somewhat loosely packed because of the churning and mixing effects of the cratering mechanism. Therefore, the sample was gently poured into the sample holder. No forced packing was applied, but the sample holder

was vibrated moderately to insure uniform settling and to rid the sample of voids.

## THE METHOD OF THERMAL CONDUCTIVITY MEASUREMENT

The differentiated line heat source thermal conductivity test method was developed by R. Merrill<sup>1</sup> and is described in detail elsewhere [5]. It is a modification of the line heat source method in which a heater wire imbedded in the sample supplies heat energy to the sample at a carefully measured level. A thermocouple wire near the heater wire measures the temperature rise in the sample. In the DLHS method, the temperature rise per unit time is computed electronically, and the curve  $dT/dt$  (Fig. 1) is printed out on a strip chart recorder. The thermal conductivity,  $K$ , can be derived from either of the following relationships:

$$K = \frac{0.37337 \text{ BoBi}}{e e_{cm} t_{\frac{1}{2}}} \quad (1)$$

$$K = \frac{4.361 \text{ BoBi}}{e e_{cm} t_{\frac{1}{2}}} \quad (2)$$

where  $\text{Bo}$  is the heater power,  $e$  is a constant,  $e_{cm}$  is the difference between the initial and maximum voltage change per unit time, and  $t_{\frac{1}{2}}$  is the time (in seconds) it takes to reach one half of  $e_{cm}$  measured from the onset of heater power. The value for  $t_{\frac{1}{2}}$  is the time it takes to reach the one half point of  $e_{cm}$  for the second time, that is, on the negative slope side of the  $dT/dt$  curve (Fig. 1) and  $\text{Bi}$ , an amplification factor, is found from the equation

$$\text{Bi} = \frac{\text{RC} \alpha 100}{S_1 S_2 \times 10^{-12}} \quad (3)$$

where  $\text{RC}$  is the time constant of a differentiating network,  $\alpha$  is the temperature coefficient of the thermocouple, and  $S_1$  and  $S_2$  indicate the ranges of the two microvolt amplifiers used.

1. His dissertation at Brigham Young University was titled "Thermal Conductivity Through an Evacuated Idealized Powder Over the Temperature Range of 100 to 500°K."

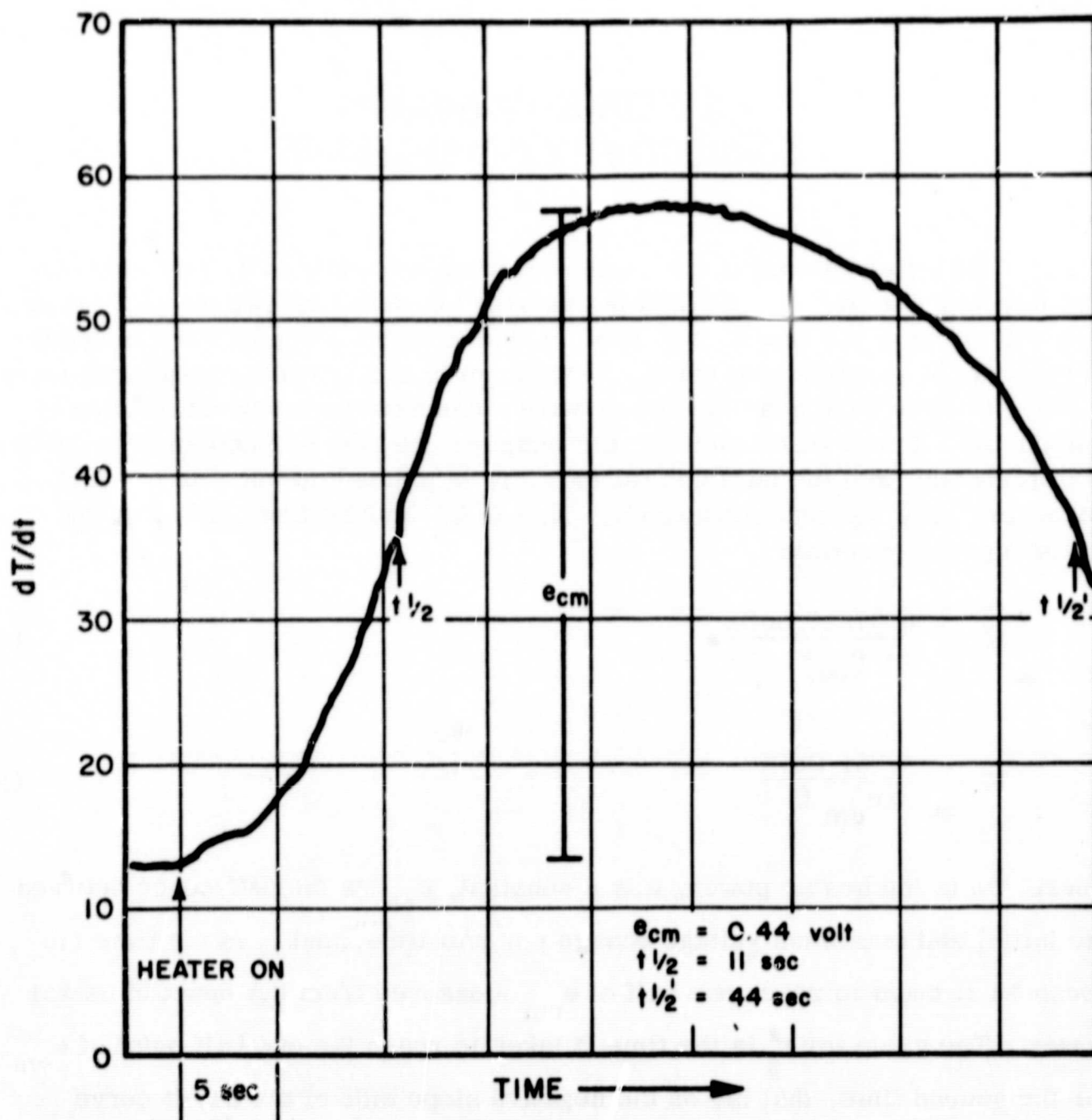


FIGURE 1. TIME DERIVATIVE OF TEMPERATURE VERSUS TIME

Equation (1) with  $t_{\frac{1}{2}}$  is used when measuring very low thermal conductivities. When the  $\text{CO}_2$  gas was introduced into the system, the thermal conductivity rose to such a level that  $t_{\frac{1}{2}}$  occurred rapidly. The time response of the recorders and amplifiers was pushed to the point that the error in establishing the time that  $t_{\frac{1}{2}}$  occurred was too great. Therefore, when  $t_{\frac{1}{2}}$  was less than 16 seconds, equation (2) with  $t'_{\frac{1}{2}}$  was used.



## TEST RESULTS

The test results are presented in Table I. The thermal conductivity values in the simulated Martian environment range from  $1.53 \times 10^{-4}$  watt/cm $^{\circ}$ K at the lower temperatures to  $2.35 \times 10^{-4}$  watt/cm $^{\circ}$ K at the higher temperatures. Figure 2 shows a semi-log plot of conductivity values over a temperature range approaching that of the lunar environment (1) at a clean vacuum of  $1 \times 10^{-8}$  torr and (2) in a pure CO $_2$  atmosphere at 7 mb pressure. The high vacuum data are taken from Scott [ 5 ]. The most significant result is the approximately one order of magnitude increase in thermal conductivity when one changes from lunar-type conditions to Martian conditions.

These results are in surprisingly good agreement with similar work done by A. D. Little, Inc. (ADL), under contract to the Space Sciences Laboratory on glass beads as a function of atmospheric pressure [6]. Figure 3 shows the ADL data, a plot of thermal conductivity (at room temperature) as a function of pressure. Using their line heat source values for the 29  $\mu$  diameter particles in the  $10^{-4}$  torr range,  $2.5 \times 10^{-5}$  watt/cm $^{\circ}$ K is in good agreement with the authors'  $10^{-3}$  torr data value of  $1.75 \times 10^{-5}$  watt/cm $^{\circ}$ K (read at 300 $^{\circ}$ K). The ADL value of  $2 \times 10^{-4}$  watt/cm $^{\circ}$ K at 7 mb agrees with the authors' value of  $2.07 \times 10^{-4}$  watt/cm $^{\circ}$ K. This value was read from the curve for the 50  $\mu$  diameter particles (lower curve) since this particle size was closest to the authors' sample particle size of  $34 \pm 4 \mu$ .

Another interesting result is that the effects of increasing temperature on the shape of the thermal conductivity curve are not as pronounced under Martian conditions as they are under lunar conditions. Figures 4 and 5 compare the same data in Figure 2, but on an expanded scale, and show only the portion corresponding to the Martian temperature range. The solid curve in Figure 4 is Watson's expression  $K = A + BT^3$ , which was curve-fitted to the data by using a computer.<sup>1</sup> In Figure 5, the solid curve is a least squares curve fit of a second-degree polynomial,  $K = A + BT + CT^2$ . This curve was selected as the best fit from curves up to 4th degree. Reading values from the curves, it can be seen that the conductivity of the sample doubles under vacuum (Fig. 4), but increases by only about 30 percent at 7 mb CO $_2$  (Fig. 5). Under hard vacuum ( $< 1 \times 10^{-4}$  torr), solid conduction and radiation are the principle contributing factors to thermal conductivity. Since the radiation contribution to thermal conductivity is

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1. From his thesis for the California Institute of Technology, titled "The Thermal Conductivity Measurements of Selected Silicate Powders in Vacuum From 150 $^{\circ}$  - 350 $^{\circ}$ K."

TABLE I. THERMAL CONDUCTIVITY VALUES IN A SIMULATED MARTIAN ENVIRONMENT

Test No.	Temperature °K	Thermal Conductivity $10^{-4}$ watt/cm °K	Test No.	Temperature °K	Thermal Conductivity $10^{-4}$ watt/cm °K	Test No.	Temperature °K	Thermal Conductivity $10^{-4}$ watt/cm °K
355	193	1.68	368	262	2.06	386	294	1.75
339	200	1.53	385	262	1.90	387	294	2.12
356	203	1.73	352	263	1.85	404	294	1.95
380	208	1.55	369	264	1.90	405	294	2.09
35	210	1.71	353	265	1.64	406	294	2.10
357	213	1.63	393	267	1.94	407	294	2.12
341	217	1.71	354	267	1.87	408	294	2.12
342	223	1.62	370	267	1.96	409	294	2.12
358	223	1.71	371	269	1.98	410	294	2.03
359	225	1.74	372	270	1.97	385	295	1.96
360	229	1.80	394	273	2.00	386	295	1.94
343	229	1.71	373	274	2.09	387	295	1.97
344	233	1.65	374	276	2.01	388	295	1.81
361	233	1.83	375	277	2.02	389	295	2.08
362	237	1.65	376	278	1.89	390	295	2.19
345	237	1.87	379	278	1.78	391	295	2.13
346	240	1.98	378	279	2.08	401	295	1.95
382	241	1.80	395	281	2.21	403	295	2.28
363	242	1.84	396	282	2.22	402	296	2.35
347	245	1.86	397	284	2.22	411	297	2.24
364	247	1.85	398	286	2.19	430	301	2.16
383	248	1.84	399	287	2.24	431	301	2.15
348	250	1.76	400	289	2.06	432	301	2.03
365	251	1.95	327	293	2.06	422	304	2.00
366	256	2.06	328	293	1.89	425	304	1.95
349	257	1.95	329	293	1.86	426	304	2.30
367	259	2.04	331	293	2.25	427	304	2.50
392	259	1.69	332	294	1.88	428	304	1.96
350	260	1.89	333	294	1.97	412	305	1.99
351	261	1.69	334	294	2.10			

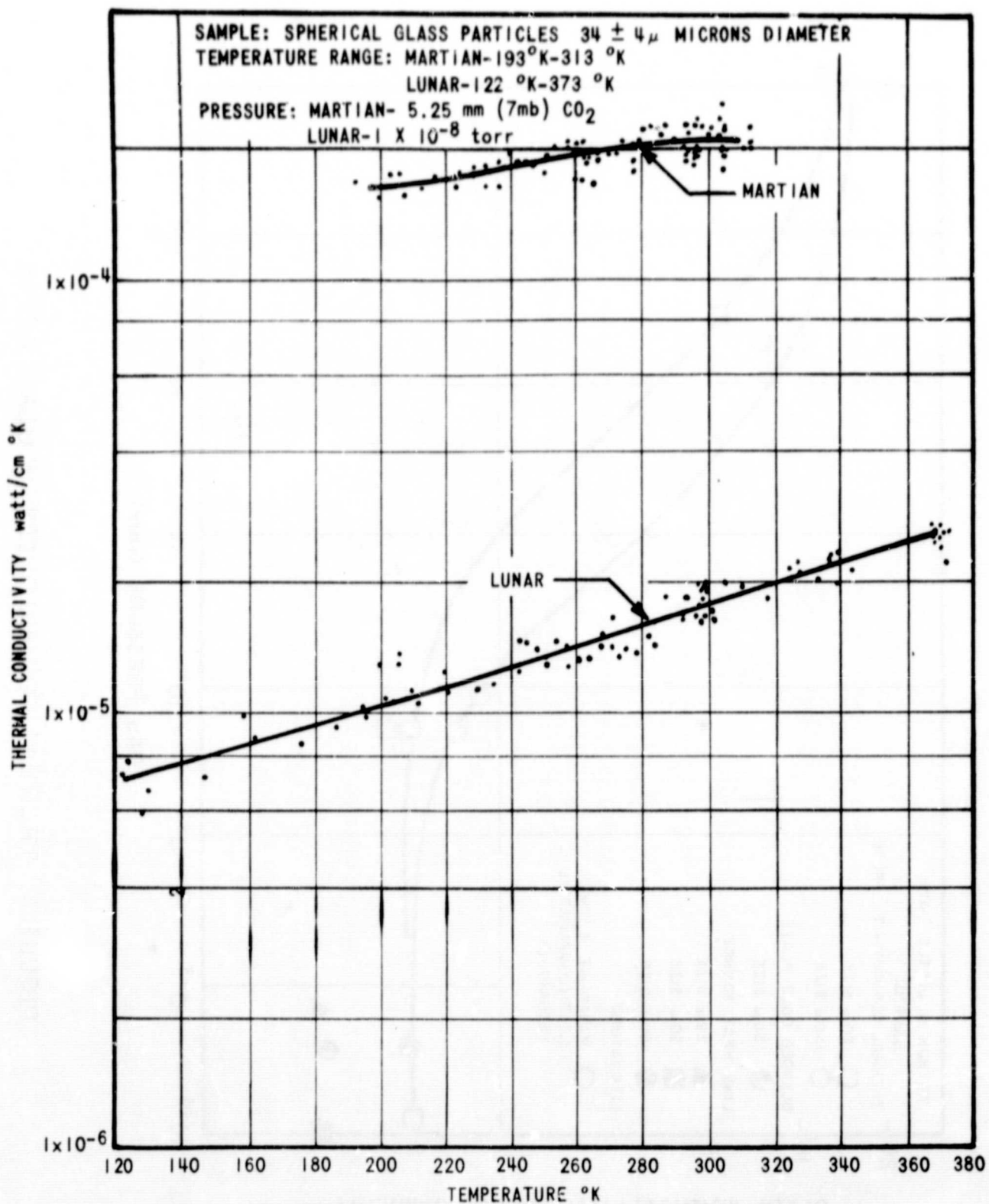


FIGURE 2. THERMAL CONDUCTIVITY OF PARTICULATE SAMPLE UNDER SIMULATED MARTIAN AND LUNAR ENVIRONMENTS



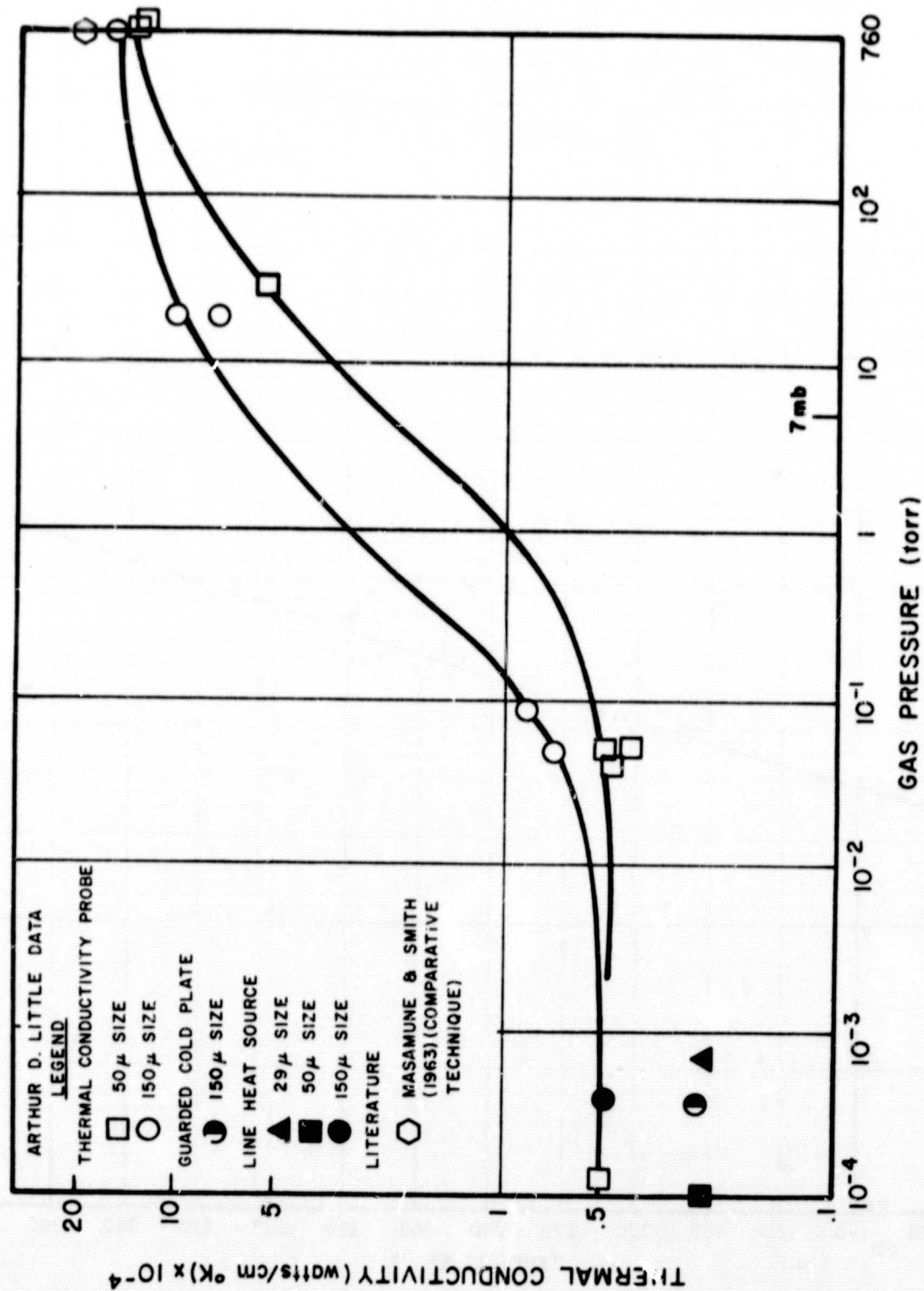


FIGURE 3. THERMAL CONDUCTIVITY OF GLASS BEADS

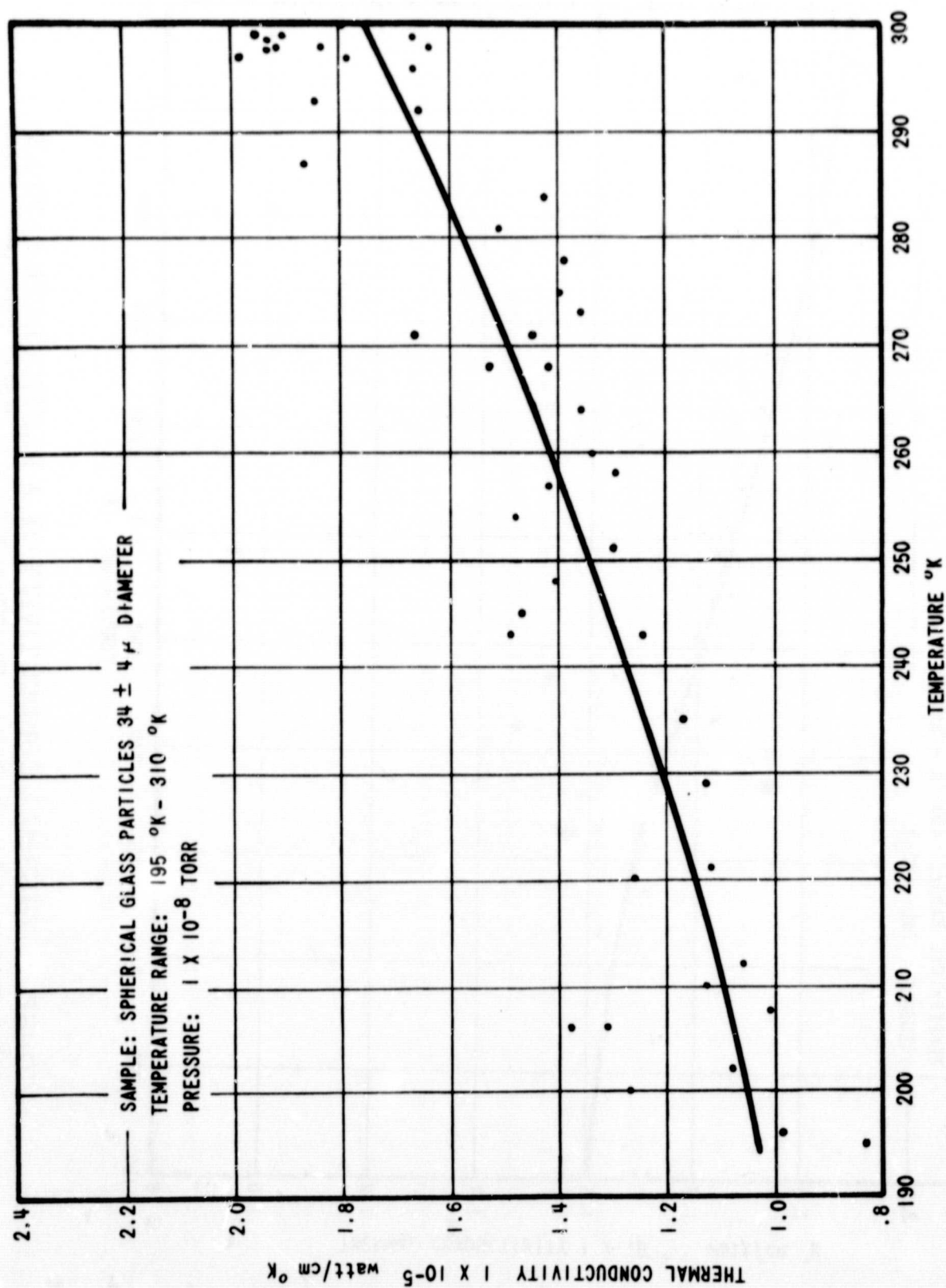


FIGURE 4. THERMAL CONDUCTIVITY OF A PARTICULATE SAMPLE  
(UNDER VACUUM) VERSUS TEMPERATURE

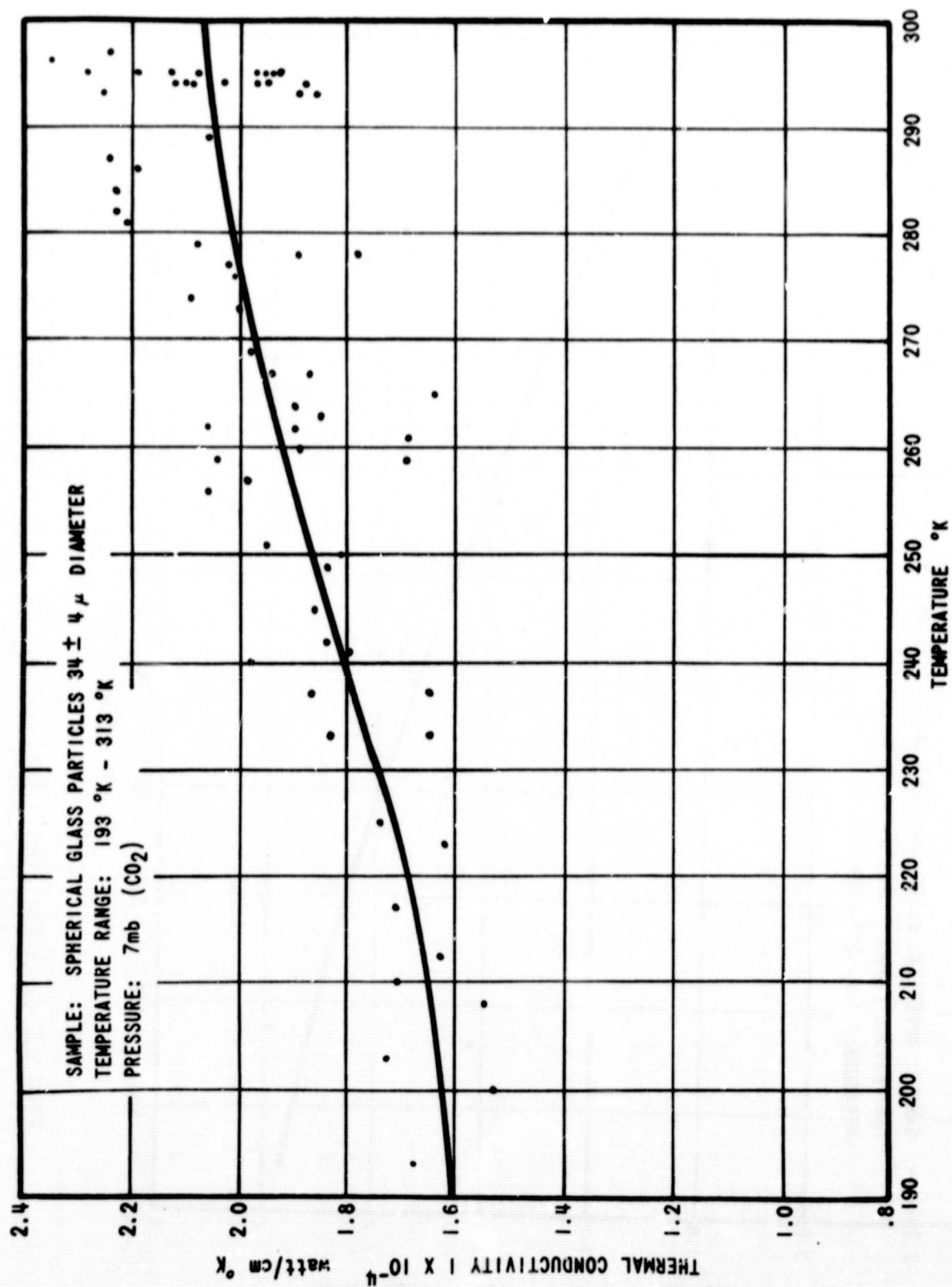


FIGURE 5. THERMAL CONDUCTIVITY OF A PARTICULATE SAMPLE UNDER SIMULATED MARTIAN ENVIRONMENT VERSUS TEMPERATURE

directly proportional to the third power of the absolute temperature, increasing the temperature substantially increases the thermal conductivity. With a gaseous heat conductor filling the interstitial space between the particles, the dominant mode of heat transfer is gaseous convection, and the radiation increase is overshadowed.

In general, it has been shown that the Martian surface will be a better conductor of thermal energy than the lunar surface by about an order of magnitude, because of the presence of a gaseous atmosphere. Also, the Martian environment will provide a moderating effect on thermal problems relating to the temperature extremes, partly because the temperature extremes are simply not as great as they are on the moon, and partly because of the effect of the gaseous nature of the atmosphere.

## OTHER MARTIAN MODELS

Other models of the planet Mars have been suggested in the past. DeVaucouleurs, Hess, and Kuiper have given values that show as much as 93.8, 93, and 85 percent nitrogen, respectively. A heavy nitrogen content has been discounted in recent observations, but tests showing the effects of a nitrogen atmosphere could be done. However, because of the similarity in the conductivity of the two gases, and the close agreement between the ADL data and the authors', it appears that a nitrogen gas-particulate material sample would give results similar to the authors' in Figure 5.

Limonite has been proposed as a candidate for a Martian mineral type [7]. This has been discounted by Sinton [8], but in the absence of any other applicable choice, a limonite sample will be used in future experiments. Also, with the assumption that the terrestrial planets and their satellites are similar in composition, other terrestrial samples such as basalt (which has been mentioned as a possible lunar candidate) will be tested.



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